PROBLEMS OF PETROGRAPHIC CLASSIFICATION SUGGESTED BY THE "KODURITE SERIES" OF INDIA[1]

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INTRODUCTION

Petrographic classification has often been retarded or sent on the wrong course, for a time, by the repeated failure of petrographers, often those of deserved reputation as investigators, to observe some broad principles of systematic classification. A petrographic system which is to endure must surely be constructed with the aid of generalizations or other factors which are widely applicable to the rocks of the earth. Premature generalizations have always proved harmful when introduced into system, however helpful they may have been in their proper places, as aids in the study of particular problems. Broad system expresses general relationships of certain kinds, but many systematic propositions or criticisms are made with a desire to emphasize the peculiarities of the rocks of a locality, a district, or, at most, a province. I desire to offer a few observations on this last point apropos of a recent discussion by L. L. Fermor, and this leads to some comments on the classification of igneous rocks contained in Hatch's well-known *Textbook of Petrology*.

A recent publication by Fermor,[2] referring to both local and general problems of petrographic classification, raises a number of questions of more than passing interest. Certain manganiferous rocks of India called the "Kodurite Series" are believed by Fermor to be "a series of differentiated igneous rocks ranging in acidity from quartz-orthoclase rock, through intermediate quartz-kodurites

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] L. Leigh Fermor, "The Systematic Position of the Kodurite Series, Especially with Reference to the Quantitative Classification," *Records, Geol. Survey of India*, XLII, Pt. 3 (1912), 208–30, Calcutta.

and basic kodurites, to manganese-pyroxenites containing rhodonite and other manganese pyroxenes."[1] The kodurite proper is a rock now much decomposed, but assumed to have consisted of orthoclase, a manganiferous garnet, and apatite. Opal now takes the place of the supposed orthoclase.

What are considered to be difficulties in the way of classifying the kodurite and other highly manganiferous rocks in the Quantitative System lead Fermor to conclude that it fails in several respects when applied to such rocks or to possible ones rich in nickel, barium, strontium, or lime. On the other hand, it is said that classification of the kodurite and other rare rocks by Hatch's system is eminently satisfactory.

The evident fairness with which Fermor has essayed the classification of the kodurite rocks in the Quantitative System relieves his discussion, in most respects, from the charge of controversial tone, notwithstanding his very evident prejudice against some features of that system. The problems presented by such rocks are real ones and must be solved if manganese-rich igneous rocks occur, but there is a point of view from which the result reached by Fermor is very much more satisfactory than it seems to him, as will appear in the following discussion.

THE CHARACTER OF THE KODURITE SERIES

The rocks of the Kodurite Series were specially described by Fermor[2] some years ago. They occur in the Archean Complex of the coastal plain belt of the Madras Presidency about midway between Madras and Calcutta. In view of the importance of this series, if of igneous character, it is necessary to point out at once that this character is by no means self-evident, and that much further proof than that offered by Fermor is necessary before geologists unfamiliar with the occurrence can be expected to accept the view of their igneous origin.

The kodurite rocks occur in a lowland zone of poor exposures, the best being in the manganese mines where the secondary oxi-

[1] L. Leigh Fermor, *op. cit.*, p. 208.

[2] L. Leigh Fermor, "On the Manganese Deposits of India," *Memoirs, Geol. Survey of India*, XXXVII, Pt. 2 (1909), "Geology," 243–79, Calcutta.

dized decomposition products are exploited. They appear in association with metamorphosed sedimentary rocks of the Khondalite Series, other metamorphosed sediments, rich in garnet, called "calc gneisses," a gneissose granite, and the Charnockite Series, the last two being considered of igneous origin. Fermor points out the banded arrangement of all the rocks, the absence of contacts showing intrusive relations, and the closer association of the Kodurite Series with the metamorphics than with the igneous Charnockite Series. The only cited occurrences thought by Fermor to indicate intrusive character are in two sections, five miles apart, in which the manganese rocks occupy different relations in metamorphic zones which appear to be made up of the same elements.

The principal feature of the rocks interpreted as favoring the hypothesis of their magmatic origin is the mineral and chemical composition, which Fermor believes cannot be explained in any other way.

Before proceeding to review the characters of the rocks I wish to point out that the term "series" is commonly used in India for both metamorphic and igneous rocks as a convenient term by which to group or correlate them as an aid in the analysis of the complex and obscure Archean System. When applied to igneous masses the term has still chiefly a stratigraphic sense, is used for convenience, and is subject to free modification. "Kodurite Series" is applied by Fermor to rocks assumed to have common origin through differentiation, but this view is not as yet justified by chemical investigation or adequate knowledge of relations and the name appears to be simply a practical, justifiable term of convenience for local uses.

The Kodurite Series consists of quartz-orthoclase rock, apatite-quartz-orthoclase rock, quartz-kodurite, orthoclase rock, kodurite, pyroxene-kodurite, biotite-kodurite, spandite rock, apatite-spandite rock, pyroxene-spandite rock, manganese-pyroxenites, and graphitic manganese pyroxenites. These varieties and the intermediate phases have not been described as yet in a connected manner showing the chain of peculiar characters necessary to establish a true petrographic series. But few chemical analyses are offered by Fermor.

The series is almost unique as to its manganese minerals, if they are constituents of true igneous rocks. Garnet, manganiferous pyroxenes, and graphite are, however, common constituents of associated metamorphic rocks in India. The first and heavy burden of proof is then to demonstrate that the kodurite rocks are igneous. Known field relations do not do this, as Fermor freely admits. The lack of definite evidence to the contrary scarcely permits the acceptance of the igneous origin in view of the known occurrences of the peculiar minerals.

I am perfectly willing to admit the possibility of manganese-rich magmas as differentiation products, and even assume that they will be found; so that while not regarding the evidence adduced by Fermor as sufficient to establish the Kodurite Series as magmatic differentiates, I am quite ready to discuss the problems of classification which would be presented by such rocks.

FERMOR'S QUANTITATIVE CLASSIFICATION OF KODURITE AND GARNET ROCK

Assuming that rocks like kodurite may be of igneous origin, let us review Fermor's discussion of the problems involved in the Quantitative Classification of the Kodurite Series. That discussion is based on four hypothetical or "calculated analyses." The kodurite proper is the original rock now much altered through replacement of feldspar, believed to have been orthoclase, by opaline silica. Two of the freshest rocks were analyzed, one from Kotakarra in the Vizagapatam district, and one from Boirani in the Ganjam district. Assuming the replacement of orthoclase by opal, Fermor made an estimate of the original mineral composition of these rocks. The former is thought to have consisted of: apatite 3.36, garnet (spandite) 55.04, orthoclase 41.29, TiO_2 0.29, CuO 0.02; the latter of apatite 2.62, orthoclase 57.80, albite 2.79, garnet (grandite) 36.55, and TiO_2 0.24. From these figures equivalent chemical "analyses" have been calculated, which serve as the basis of classification of kodurite.

The two nearly pure garnet rocks, one from each of the localities above mentioned, are assumed to have the composition of the garnets in the two kodurites, as calculated from the rock analyses.[1]

[1] *Memoirs*, etc., pp. 256–61.

Table I gives the actual analyses of the Kotakarra (I) and Boirani (II) rocks; the calculated chemical composition corresponding to the estimated original mineral constitution (I*a* and II*a*); and the calculated composition of the garnets in rocks I and II, supposed to fairly represent certain garnet rocks of Kotakarra and Boirani (III and IV). In Table II the norms calculated by Fermor from I*a*, II*a*, III, and IV are also quoted.

TABLE I

ACTUAL AND CALCULATED ANALYSES

	Kotakarra Kodurite		Boirani Kodurite		Kotakarra Garnet-Rock	Boirani Garnet-Rock
	I	I*a*	II	II*a*	III	IV
SiO_2	54.15*	47.45	60.60†	53.36	37.57	38.18
TiO_2	0.32	0.29	0.27	0.24	....	....
Al_2O_3	11.50	18.00	10.59	16.31	18.98	14.22
Fe_2O_3	6.07	1.91	4.79	4.17	3.47	11.41
FeO	0.90	4.10	0.64	0.79	7.45	2.16
MnO	10.00	9.08	1.07	0.98	16.50	2.68
MgO	0.14	0.13	0.26	0.22	0.23	0.65
CaO	11.67	10.37	13.87	12.54	15.80	30.70
K_2O	0.01	6.97	4.00	9.75	....	....
Na_2O	0.18	....	0.36	0.33	....	....
P_2O_5	1.60	1.42	1.24	1.11	....	....
CaF_2	....	0.26††	....	0.20††	....	....
CuO	0.02	0.02	trace	....	....	....
H_2O 100°+	1.33	....	1.20	....	....	....
H_2O 100°	2.30	....	1.30	....	....	....
Total	100.19	100.00	100.19	100.00	100.00	100.00

* Combined SiO_2 = 35.50: free SiO_2 = 18.65.
† Combined SiO_2 = 32.25: free SiO_2 = 28.35.
†† Calculated from fluorine assumed in apatite.

A rock having the composition of I*a* would be, as Fermor has shown, a perpotassic andase in the Quantitative System (II. 5. 3. 1); one like II*a* would be a perpotassic monzonase (II. 5. 2. 1). No perpotassic rock of either of these rangs has been described previously and Fermor proposes the names kodurose and boiranose, which cannot be accepted, as shown below.

The further quantitative classification of I*a* on the basis of the amount and chemical character of the femic constituents is carried out by Fermor in accord with the principles of the system.

Manganese is recognized by calculating its ratio to ferrous iron and establishing subsections of subgrad, one step farther than has been necessary hitherto.[1] Fermor also calculates the position of II*a* to the subsection of subgrad, but the small amounts of magnesia, ferrous iron, and manganese (together but 1.99 per cent) make it quite unnecessary to go beyond the precalcic subgrad. The hypothetical garnet rocks, III and IV, fall in the Salfemanes, and their classification is also calculated by Fermor to subsections of subgrad.

TABLE II

NORMS FROM CALCULATED ANALYSES

	Kotakarra Kodurite	Boirani Kodurite	Kotakarra Garnet-Rock	Boirani Garnet-Rock
	I*a*	II*a*	III	IV
Orthoclase	35.47	55.60	....	....
Leucite	4.53	1.61	....	....
Nephelite	....	1.50	....	....
Anorthite	28.44	14.15	51.74	38.75
Diopside	....	1.19	....	3.50
Hedenbergite	11.02	....	7.25	....
Wollastonite	0.93	16.71	....	5.49
Akermanite	....	....	6.71	34.87
Fayalite	....	....	5.80	....
Tephroite	12.93	1.39	23.47	3.80
Magnetite	2.76	1.86	5.03	6.96
Hematite	....	2.89	....	6.61
Ilmenite	0.55	0.46	....	....
Apatite	3.33	2.62	....	....
	99.96	99.98	100.00	99.98

The procedure by which Fermor provides a place for manganese-rich rocks in the Quantitative Classification is, as just noted, quite in harmony with the principles of the system, and on that score its authors have no criticism to make. But in regard to the various names proposed by Fermor, we must point out, in response to his request, that all of them are quite unwarranted and cannot be accepted since they are based on "calculated analyses" derived

[1] See Cross, Iddings, Pirsson, and Washington, "Modifications of the Quantitative System," etc., *Jour. Geol.*, XXII (1912), 552–53.

from analyses of much-altered rocks.[1] With increasing experience it becomes more and more clear that quantitative system names should be based only on good analyses of fresh or but slightly altered rocks. Fermor's "calculated analyses" are clearly liable to errors unfitting them for any systematic use, however valuable and justifiable they may be in discussing the nature of the alteration that has taken place. Kodurite of both types and the garnet rocks are, like many of their associates, very interesting and unusual types and, if their igneous character can be established and good analyses furnished, some of them will undoubtedly fall in divisions of the Quantitative System in which there are at present no other known representatives, and new quantitative names may well be based on them.

Fermor is not satisfied with the result of applying the Quantitative System to the four hypothetical rocks, and points out what he regards as the defects of the system indicated by this case. He considers it a serious flaw in the system that the subrang is reached without reference to the important constituent normative tephroite (12.93 per cent in I*a*) and further that rocks poor in manganese may fall in the same subrang. This criticism touches the fundamental distinction between salic and femic components which it seems unnecessary to discuss at this time. Other criticisms may best be expressed in the following quotations:

> There certainly seems to be something lacking in a system which takes no effective account, until the ninth subdivision of the system is reached, of a constituent that is fourth in order of importance in the chemical analysis and third in order of importance in the norm.
>
> The same criticisms apply to boiranose, but to a much smaller degree on account of the much smaller amount of MnO present; but they apply in an even more striking manner to the Kotakarra garnet-rock (spandite-rock), in which MnO is third in order of importance in the chemical analysis, and tephroite, Mn_2SiO_4, is second in order of importance in the norm, of which it forms nearly 25 per cent.[2]

[1] Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks*, p. 166. This and all other references to the Quantitative System contained in this paper are made with full approval of my colleagues. A review of all names proposed since the Quantitative System was first published will be given by Dr. Washington in a forthcoming new edition of his *Chemical Analyses of Igneous Rocks.*

[2] *Records*, p. 217.

The natural reply to all such criticisms is mainly a reference to certain principles which must be recognized in any systematic classification of igneous rocks. Fermor clearly desires a method of classification specially adapted to the peculiar "Kodurite Series," the rocks he happens to be working with. But a local or provincial "series" is not and cannot be made a broad systematic concept. Such a series has certain features or characters common to other series, but that which specially characterizes a local series is surely not a factor to be prominently introduced into systematic classification of rocks in general. Any comprehensive system must recognize first the factors which are important because common to, though variable in, many rocks, and later take up those which are notable in addition as distinguishing a few.

General petrographic system must bring out through classification the relations of kodurite to other rocks, as well as its peculiarities. The hypothetical kodurite has other notable chemical characters besides its manganese contents. It is assumed to be remarkably rich in potash and poor in soda; rich in lime and poor in magnesia. It is these characters that show the relation of such a type to other rocks, not the unique richness in manganese. To express these broader relations is the object of systematic classification, and it is these factors of general chemical relationship which are logically applied in the Quantitative System.

An igneous rock having the composition assumed for kodurite would be a new and interesting magmatic variety irrespective of its manganese, through its quite abnormal association of high lime and potash with low magnesia and soda. The Boirani kodurite possibly falls in another perpotassic subrang, of higher lime contents even in its salic molecules, and still more markedly calcic in its femic constituents, than kodurite proper. These facts are just what a logical system should bring out before the unusual richness in manganese finds expression. No system can be constructed permitting the application of each of the many chemical elements of igneous rocks in accordance with its order of prominence in each case, now first, now fifth, now tenth.

From this point of view the fact that the unusual richness of the Kotakarra kodurite in manganese finds expression in the

eighth place in the Quantitative System seems quite appropriate. It is certainly plain that a scheme recognizing manganese in the third place would, for example, not serve to bring out the actual close relationship which exists between the Boirani and Kotakarra kodurites, for the former has only 0.98 per cent MnO. Fermor himself points out that, considering manganese as the characteristic thing about kodurite, the Boirani rock is classed with it simply for convenience. It is modal garnet and orthoclase or normative anorthite and orthoclase which bring the rocks together.

Fermor expresses the opinion that the Quantitative System does not possess either the elasticity or the comprehensiveness which the writer has said should be found in a satisfactory classification. If by elasticity is meant the possibility of transposing certain fundamental parts of the structure at will, according to the varying prominence of certain constituents in different rocks, the first part of this comment is true, but it may be answered that no real *system* can be so constructed. The section of subgrad necessary to express the manganiferous character of kodurite is, however, not an *appendix*, as Fermor considers it. It is an extreme division of the system connected appropriately with the rest in a manner provided for in the original publication.

"Kodurose," as a subgrad magmatic name, does not itself express all the chemical relations involved, but it is no more necessary to go over all the steps of the classification by which this division has been reached, whenever it is referred to, than it is in using the specific or varietal names of animals or plants. It may be pointed out that where the chemical relations of igneous rocks are in question, the new symbols for expressing quantitative classification do show the whole systematic position far better than does any existing scheme for concise statement in zoölogy or botany.[1] "Kodurose" does express the important relationships of such a manganese rock to other rocks in all important respects—when the system is understood.

Fermor considers the Quantitative System unable to deal with rocks containing large amounts of oxides of manganese, nickel,

[1] Cross, Iddings, Pirsson, and Washington, "Modifications of the Quantitative Classification," etc., *Jour. Geol.*, XX (1912), 553–57.

barium, strontium, etc., because the system, as published, does not contain all the detail applicable to such cases. He cites, however, the remark by the authors of the system that the above-named oxides are to be grouped with FeO or CaO "unless these unusual components occur in sufficient amounts to make their calculation as special mineral molecules desirable." It was believed by the authors that the principles and methods of the system were so clearly illustrated by the scheme published that petrographers would understand the extension of the framework of the system to rocks in which any rare elements might acquire local prominence. Fermor's treatment of the manganese rocks is in accord with that assumption.

With regard to *sections* it was remarked:

> The application of the above principles [used in the construction of the system] shows, however, that in certain points more numerous subdivisions are needed. This necessity is met by the formation of *sections* of any of the divisions above described. These sections will be based on more special characters according to circumstances.[1]

It is of course possible that igneous rocks may sometime be found containing in notable amounts rare substances which must be introduced into the norm, and where the exact method of procedure in systematic treatment may not be plain. But even in the case of barite, raised by Fermor, its position in the group A of femic molecules is appreciated by him and the recognition of the various molecules of this group in the system, while somewhat complicated, will not prove very difficult. Until the occurrence of barite as an original constituent of igneous rocks is conclusively demonstrated it seems unnecessary to work out the details of its treatment in the Quantitative System. The igneous nature of the quartz-barite rock of Salem, India, mentioned by Fermor, can hardly be considered as proven, at the present time. The new divisions of the Quantitative System which may be made necessary for rocks of unusual chemical composition will not be appendices of the system, in the sense of unrelated appendages.

[1] *Op. cit.*, p. 127.

CLASSIFICATION OF KODURITE SERIES BY HATCH'S SYSTEM

While Fermor considers the Quantitative Classification of the Kodurite Series unsatisfactory, as illustrated by the four hypothetical rocks specially discussed, he states that he is able to classify the whole series with ease and accuracy in the modified form of the mineralogical system recently proposed by F. H. Hatch,[1] and draws the attention of the American petrographers to the "elasticity of Hatch's classification."[2] Believing the kodurite rocks plutonic, Fermor adds "a mangan-subseries of the potash series" and introduces the Kodurite Series intact, with its new names, in Hatch's system. Whether Hatch considers this claim for the elasticity of his system correct or not I do not know, but I do not understand that *any* existing system permits the introduction of local or provincial series as such in its framework.

The discussion of Fermor's procedure in applying Hatch's system to the Kodurite Series may well be left to the author of that system, but, as one who has studied the subject of systematic classification of rocks from many standpoints, I wish to make the comment that the principles of general system and the considerations that control in the expression of provincial characteristics in a so-called "rock series" are almost antithetical. A scheme containing three or four such series intact would cease to be a system. The term "series" is applied by Hatch and Fermor to very different concepts.

It would seem to me that the case of the Kodurite Series was directly covered by the following statement of Hatch:

> Although names founded on mineralogical variation in constituents other than the feldspars are of little service in classifying rock-types, they are often useful for descriptive purposes. They form no part, however, of the system of classification now undergoing discussion.[3]

HATCH'S PETROGRAPHIC SYSTEM

The classification of igneous rocks presented by Hatch in the fifth edition of his *Textbook of Petrology* (1909), and repeated in

[1] F. H. Hatch, "The Classification of the Plutonic Rocks," *Science Progress*, October, 1908; *Textbook of Petrology*, 5th ed., 1909; 6th ed., 1910; 7th ed., 1914.

[2] *Records*, p. 225. [3] *Science Progress*, p. 7.

later editions, is very nearly the same, in effect, as other forms of the mineralogical system which have been in use for many years past. But he introduces certain new factors, intended to give the system greater precision and a quantitative character hitherto wanting. Because of the frankly expressed object of the author to formulate a classification free from the, to him, objectionable features of the Quantitative System, it seems appropriate to review some features of the revised system. I wish to emphasize the fact, however, that the critical comments to be made are, almost without exception, of general application to many earlier propositions and are not personal to Hatch.

The attitude of Hatch toward the Quantitative System and the claims made for his own scheme are in part expressed in the following quotations:

> In the quantitative classification of igneous rocks devised by Messrs. Whitman Cross, Iddings, Pirsson, and H. S. Washington, the hitherto existing nomenclature of rock types is entirely discarded, and a new nomenclature introduced which is based on purely chemical considerations without regard to mode of origin. . . . .
>
> I desire in this paper to show that it is not necessary to throw over the existing rock nomenclature, nor to *disregard mode of origin, in basing a natural system of classification on chemical considerations.*[1]

The element in Hatch's system which underlies the claim that it is a "natural system" is the primary division by "mode of occurrence" into plutonic, hypabyssal, and volcanic rocks. Mode of occurrence is, indeed, a criterion for the classification of igneous rock masses, and Hatch devotes a chapter to this subject. Where this primary division is made, Hatch points out that "volcanic rocks are, however, connected with their deep-seated or plutonic roots by necks and pipes, or by dikes. A third division of igneous rocks is therefore necessary to embrace these connecting links between plutonic and volcanic rocks. For this division the term *hypabyssal* is used."[2]

But neither Hatch nor any other systematist using plutonic in this sense necessarily means deep-seated or abyssal. He means granular, and yet it is known that certain granular rocks, treated

[1] *Science Progress*, p. 1. Italics by W. C.

[2] *Textbook of Petrology*, 5th ed., pp. 7 and 8; 7th ed., pp. 5 and 6.

as plutonic, occur side by side with rocks termed hypabyssal, and some have been formed near if not at the surface. In treating the hypabyssal rocks, Hatch shows that he is largely influenced by Brögger's proposition to apply this term to the "Dike rocks" of Rosenbusch. The complex genetic, structural, and textural relations involved in this conception are well known and need not be stated here. And in view of an earlier discussion of this subject[1] I need only repeat that the use of these natural relations of rocks in classification must be appropriate and consistent with the facts, or the result is *unnatural*.

The expression "natural system" as applied to petrographic classifications should, I think, refer to other things as well as to the use of factors of natural occurrence. The rocks themselves have various *natural* characters or properties. The systematist makes use of these characters in classification and should do so as appropriately and consistently as possible. In proportion as the nature of rocks is rationally applied in their classification the result may be termed a natural system. It is with reference to this idea that the further systematic propositions adopted by Hatch will be considered. They are, for the most part, not new.

The next step is the distinction between feldspathic and non-feldspathic rocks. The two groups of substances indicated by this division occur in rocks in all amounts from 0 per cent to 100 per cent for each. If this varying constitution of two exclusive groups of minerals is to be used as a systematic factor in classification, is it not the natural way to recognize the varying proportions of the two groups? To call all rocks distinctively *feldspathic* which contain as much as 10 per cent of feldspar is to ignore the fact that rocks with 10 per cent or more of pyroxene are by the same measure *pyroxenic*. In short, this is a quite unnecessarily arbitrary and unnatural procedure and opposed to the almost universal tendency of modern petrographers to introduce a quantitative element into system wherever it is appropriate and feasible.

It is to be presumed that "chemical considerations" lead Hatch to form three groups of rocks called *acid*, *intermediate*, and *basic*,

[1] Whitman Cross, "Natural Classification of Igneous Rocks," *Quar. Jour. Geol. Soc.*, LXVI (1910), 470–506.

marked off by the percentages of silica shown on analysis, the lines being drawn at 66 and 52 per cent. These limiting percentages are admitted by Hatch to be "quite arbitrary" but permitting "a convenient separation in accordance with existing records of rock types."[1] The meaning of the latter phrase is not clear to me. Now it must be self-evident that no *chemical* consideration of importance, to say nothing of a principle, requires or suggests a division of igneous rocks by any special silica percentages whatever. Calling the group with more than 66 per cent SiO_2 "acid," and designating all the rocks of this group as the "Granite Family," implies that only rocks of this silica content may contain important amounts of quartz. The application of the name "Syenite Family" to alkalic rocks of the intermediate group implies that they must be quartz-free, or nearly so. And the designation of the group with less than 52 per cent SiO_2 as "basic" implies the generalization that quartz is absent and that silicates of such rocks must be less rich in silica than those of the intermediate group.

The well-known facts are that many rocks having less than 52 per cent SiO_2 contain metasilicates and several per cent of free silica; many intermediate rocks carry 25 to 30 per cent of quartz; and many of 66 per cent carry little or no quartz. It is a fundamental principle, ignored by Hatch, that the petrographic importance of the silica contents of a rock, as influencing the development of its minerals on crystallization, can be determined only by a study of the relative amounts of the associated bases and recognition of their influence in the magmatic solution. This principle is illustrated by the normative calculations on which the Quantitative System is based.

The fact that the silicity[2] represented by 66 per cent SiO_2 has no relation to the presence of free quartz is illustrated by three analyses quoted by Hatch in tables representing the Calc-Alkali Series.[3] In Washington's tables it is shown that the granodiorite of SiO_2 68.65 has 24.2 per cent normative quartz; the tonalite of

[1] *Science Progress*, p. 2.

[2] A useful term of self-evident meaning recently proposed by Washington (this *Journal*, XXII [1914], 16).

[3] *Science Progress*, p. 9.

SiO_2 63.09 has 22.9 per cent normative quartz; the quartz diorite of SiO_2 57.41 has 11.5 per cent normative quartz. Many rocks are nearly normative in their quartz contents and some carry more than the normative amount.

The ultrabasic rocks furnish further evidence, if such is necessary, that a division of rocks by silica percentage is without reason and without object so far as any relation between chemical and mineral composition is concerned. The line of 52 per cent silica, established by Hatch between intermediate and basic rocks, is passed by the silica of some rocks placed by him in the *ultrabasic* group, e.g., websterite, one analysis of which, cited by him, has 53.25 per cent SiO_2.

The norms of many of Hatch's ultrabasic rocks contain 20 per cent or more of feldspar and lenad. And while such amounts are not common in the *mode* of the plutonic rocks in question, those of the surface or hypabyssal forms of equivalent chemical composition are often notably feldspathic. This well-known variation in mineral composition, due to physical conditions, must be considered in any adequate systematic treatment of the more basic or "ultrabasic" rocks.

After the arbitrary division on silica percentage, Hatch introduces the character of the feldspars and feldspathoids as the factor for the next subdivision. It is his evident intent to emphasize the quantitative element in many places, but this is often by use of the vague terms "predominant," "largely developed," and "subordinate." The meaning attached to such terms is often highly subjective, as appears most striking in the case of the "Feldspathoid Series," which is defined as one "in which nepheline, sodalite, or allied feldspathoid is largely developed, and feldspar subordinate."[1] But Hatch cites, as illustrating the "Feldspathoid Series," the average of nine typical nepheline syenites, given by Brögger, and the norm calculated from this, which must approximate closely to the mode, gives feldspars 69.11 per cent, and nephelite 20.3 per cent. That is, the feldspars, which must be more than three times as abundant as nephelite in a rock of the cited composition, are declared "subordinate," and the nephelite

[1] *Science Progress*, p. 3.

relatively "largely developed." Many phonolites, foyaites, and nephelite syenites carry but 10 per cent or even less of feldspathoid. There is no indication of the minimum amount of nephelite or leucite which Hatch would consider as placing a rock in the "Feldspathoid Series."

In subdividing the feldspathic rocks still farther, Hatch introduces as a direct quantitative factor the relative percentages of alkali feldspars as against plagioclase, and of soda as contrasted with potash feldspar. This is certainly a step in the right direction, but as it comes after the irrational silica distinction, it loses much of the value it might have in bringing allied rocks together.

It is to be hoped that Fermor will succeed in establishing the origin and chemical character of the interesting rocks called the Kodurite Series. If they possess the characters assumed for them, it appears to me that the Quantitative System will show—so far as it professes to go, that is, in expressing chemical characters—both their general chemical relations to other rocks and their unique special features.

The use of factors of natural occurrence in the classification of igneous rocks does not necessarily make the system natural. The system of Hatch, like many others of allied construction, does not seem to me to use natural factors in a rational way And as actual characters of the rocks are used with unnecessary arbitrariness the right of his and allied systems to be termed natural is open to question.

The systematic treatment of igneous rocks, with all their widely varying important characters, is a matter of great difficulty, and a long time may elapse before petrographers come to a common point of view. It is in the hope of contributing, however slightly, to this understanding, that this discussion has been written.